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Thoughts on Water Beetles in a Mediterranean Environment

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Additional information is available at the end of the chapter

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Abstract

The chapter provides data from a survey carried out on water beetles in various freshwater ecosystems in Tunisia as a Mediterranean country of considerable diversity. Studies dealing with these insects are fragmentary not only in comparison with the European fauna but also in comparison to other zoogeographical areas. A compiled checklist of beetle species collected from Tunisia is given with an insight on new recorded species. Diversity, altitudinal distribution, and geographical pattern of water beetles in Northern Tunisia are discussed with regard to other Mediterranean areas. They include various chorotypes related to the history of the Mediterranean basin. Several species are threatened and require conservation. According to the criteria of the IUCN, several water beetle species can be included in the list of threatened species.

Keywords: water beetles, diversity, phenology, biogeography

1. Introduction

Water beetles are holometabolous insects characterized by a strongly sclerotized body with the forewings hardened into elytra [1]. They occur in a wide variety of habitats, living in virtually every kind of fresh- and brackish-water habitat, from the smallest ponds to lagoons and wetlands and from streams to irrigation ditches and reservoirs [2]. They exhibit high species richness in the Mediterranean area and are primarily found in the ecotone between land and inland waters [3]. They are of great ecological interest as bioindicators of the quality of limnic ecosystems, the type of water, and habitats in danger [4]. Tunisia, a Mediterranean country, has important water beetles diversity. Studies dealing with these insects are fragmentary not only in comparison with the European fauna but also in comparison to other zoogeographical areas [5–16]. Synonymy of species is established by following the “*Catalogue of Palearctic*

Coleoptera, vol. 2" edited by Löbl and Smetana [17]. Abellán et al. [2] developed a system for ranging species according to their conservation priority or vulnerability on local, national, and global scales. IUCN [18] also gave rigorous criteria and categories that should classify the species according to extinction opportunities for a given period. Of particular interest, Northern Tunisia has endemic biota under increasing anthropogenic threats, where several species require conservation [19].

The fauna of North Africa could be considered as originating from the passage of Euroasian species to the African continent as a result of plate tectonics, leading to the connection of the two continents. The Mediterranean and the Atlantic were later connected (in the Pliocene), thereby isolating the two continents [20]. Water beetles of Tunisia include various chorotypes related to the history of the Mediterranean basin of which Tunisia is a part. The northern part of Tunisia includes two mountain ranges: the Tell (Kroumir and Mogods Mountains) and the Dorsale (Châambi Range reaching the Cap Bon Peninsula) [21]. Tunisia has a humid to Saharan climate. The humid area is limited to the Kroumir Mountains [22]. Annual rainfall decreases from the north to the south, with most of the rainfall in winter [23]. Water resources are unevenly distributed within the country; the northern part, covering an area of only 17% of the territory, has 60% of the total water resources [24]. This highly influences the water permanence and, therefore, the phenology, composition, and distribution of the water beetles' communities. We analyze the faunistic, chorological, and phenological aspects of the aquatic coleopteran species in the study area.

As the species distribution is determined by a set of ecological and historical filters acting on several spatial and temporal scales [25], we analyze the assemblage of aquatic beetles in response to environmental variables characterizing the explored streams.

Understanding patterns in biological diversity along major geographical gradients is an important topic in ecology. Garrido Gonzalez et al. [26] reported that the species distribution of water beetles was greatly influenced by altitude affecting the characteristics of aquatic settings. We tested if such finding is similar for the coleopteran fauna in Northern Tunisia.

2. Knowledge status of water beetles

Previous to the exploration of Northern Tunisia during the last years, very little was known of the water beetle fauna of Tunisia. So far as can be ascertained, there are only a few published notes on their biogeography, and the other a compiled checklist of 214 species collected by [5–16, 27–34]. Compilation of studies focusing on taxonomy of water beetles of Tunisia indicated a checklist of 236 species taking into account the eventual synonymous. The result of our recent researches is a list of 123 species, including all that I have found on the Northern Tunisia (**Figure 1** and **Table 1**). It is mainly the result of monthly collecting surveys over the course of a year (May 2005–April 2006), supplemented by some species collected by friends while working at other groups of insects. We considered only the water beetles' families sampled in the recent survey. About 1420 species in about 40 genera belong

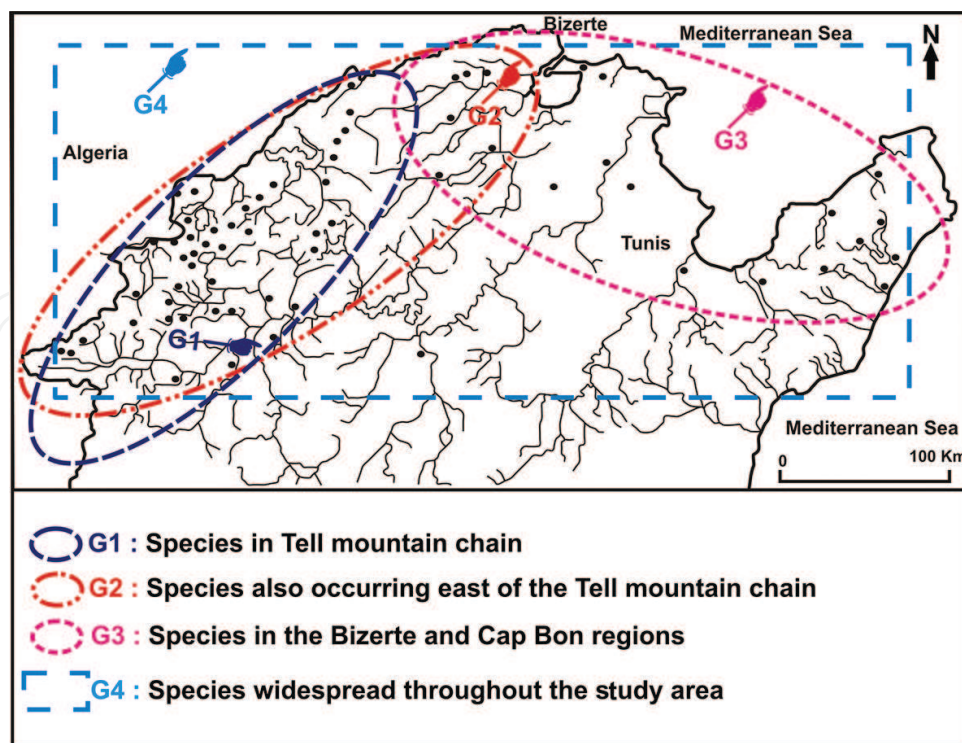


Figure 1. Map showing sampling sites and distribution of water beetles in the study area.

to Hydraenidae Mulsant, 1844 and are encountered on all continents, and some inhabit even the Subantarctic Islands, where only a few insects are able to cope with the hostile climatic conditions [1]. The Hydraenids of Tunisia comprise 57 species. Recently, we sampled 24 species including four recorded for the first time in Tunisia: *Hydraena atrata*, *Hydraena scabrosa*, *Ochthebius mauretanicus*, and *Ochthebius mediterraneus*. *Limnebius irmelae* is also an endemic species and thus require protection with regard to the anthropogenic threat on its habitat. By the North African scale, *H. atrata* shows demographic and geographic scarcity [19, 35]. Several species (*Hydraena rivularis*, *Hydraena numidica*, *Hydraena pici*, *Limnebius nitifarus*, *Limnebius theryi*, and *O. mauretanicus*) have their distribution area restricted to the extreme northern part between Algeria and Tunisia, and they could be considered as threatened species (reduction of their numbers and their biogeography). According to the criteria of the IUCN [17] for threatened species, we suggest the inclusion of *Hydraena kroumiriana* in the national red list of protected species [19].

Elmids occur on all the continents with about 1330 species in 146 genera. Members of this family are generally living in lotic habitats, and very few species are encountered on lake shores or in ponds, whereas Dryopids are represented by about 300 species in 33 genera occurring in all biogeographical regions, except for the Australian continent. Larvae are generally riparian or terrestrial; adults of about 75% of the species are regarded as aquatic (lotic and lentic habitats), and the remaining ones are riparian or terrestrial (humicolous and arboricolous) [1]. Studies on Elmidae and Dryopidae [13, 15, 31] reported 18 species. We collected nine species (Table 1), four of them are new recorded from Tunisia; *Oulimnius troglodytes*, *Potamophilus acu-*

Species	PH	CH	D	I (L;E)	"G"	Species	PH	CH	D	I (L;E)	"G"
<i>Hydraena testacea</i> ^{*2,3}	F	EM	G1	0.0804	2.75	<i>Helophorus algiricus</i> ^{*1,2,3}	F	NA	G2	0.0407	2.423
<i>Hydraena atrata</i> ¹	S	EM	G1	0.0042	1	<i>Helophorus asturiensis</i> ^{1,2,3}	F	WM	G4	0.0078	1.85
<i>Hydraena rivularis</i> ^{1,2,3}	P	NA	G4	0.0047	2.086	<i>Helophorus cincticollis</i> ^{1,3}	S	WM	G4	0.0154	2.342
<i>Hydraena leprieuri</i> ^{*1,2,3}	P	v	G4	0.0545	2.432	<i>Helophorus paraminutus</i> ¹	F	P	G2	0.0173	1
<i>Hydraena numidica</i> ^{1,3}	P	NA	G4	0.0381	2.689	<i>Aulonogyrus striatus</i> ^{1,2,3}	P	TEM	G4	0.0104	1.811
<i>Hydraena kroumiriana</i> ³	S	En	G1	0.0382	3	<i>Gyrinus urinator</i> ^{1,2}	P	TEM	G4	0.0223	1.352
<i>Hydraena scabrosa</i> ¹	S	NA	G4	0.0084	1	<i>Gyrinus dejeani</i> ^{1,2,3}	F	CEM	G4	0.0013	2.006
<i>Hydraena pici</i> ¹	S	NA	G1	0.0042	1	<i>Haliplus mucronatus</i> ^{1,2}	P	CEM	G4	0.0333	1.295
<i>Limnebius furcatus</i> ^{1,2}	S	EM	G4	0.0086	1.576	<i>Haliplus guttatus</i> ¹	P	M	G4	0.0218	1
<i>Limnebius irmelae</i> ¹	P	En	G4	0.0173	1	<i>Haliplus andalusicus</i> ¹	S	WM	G3	0.0042	1
<i>Limnebius nitifarus</i> ¹	F	NA	G1	0.0173	1	<i>Haliplus lineaticollis</i> ^{1,2,3}	P	SC	G4	0.0011	1.948
<i>Limnebius pilicauda</i> ^{*1,2,3}	P	WM	G4	0.0598	2.568	<i>Peltodytes caesus</i> ¹	F	P	G2	0.0312	1
<i>Limnebius theryi</i> ^{*1,3}	F	NA	G4	0.0564	2.606	<i>Peltodytes rotundatus</i> ^{*1}	P	TEM	G4	0.0846	1
<i>Limnebius perparvulus</i> ¹	F	M	G2	0.0128	1	<i>Hygrobia hermanni</i> ¹	P	TEM	G3	0.0173	1
<i>Aulacochthebius exaratus</i> ^{*1}	P	AEM	G4	0.0409	1	<i>Noterus laevis</i> ^{*1,2}	P	M	G4	0.0416	1.266
<i>Ochthebius aeneus</i> ¹	S	EM	G4	0.0128	1	<i>Laccophilus hyalinus</i> ^{1,2,3}	P	M	G4	0.0057	1.91
<i>Ochthebius dilatatus</i> ^{1,2,3}	P	EM	G4	0.0264	2.128	<i>Laccophilus minutus</i> ^{*1,2}	P	EMA	G4	0.0749	1.376
<i>Ochthebius viridescens</i> ^{*1,2}	P	TEM	G4	0.0508	1.242	<i>Hyphydrus aubei</i> ¹	P	EM	G4	0.0360	1
<i>Ochthebius punctatus</i> ¹	P	EM	G4	0.0312	1	<i>Yola bicarinata</i> ^{1,2,3}	P	EM	G4	0.0172	1.719
<i>Ochthebius difficilis</i> ^{1,2}	F	TEM	G4	0.0192	1.376	<i>Bidessus minutissimus</i> ^{1,2,3}	P	EM	G4	0.0043	2.048
<i>Ochthebius meredonicus</i> ¹	F	WM	G4	0.0128	1	<i>Hydroglyphus geminus</i> ^{1,2,3}	P	EMA	G4	0.0017	2.082
<i>Ochthebius mauretanicus</i> ¹	F	NA	G3	0.0084	1	<i>Hydroglyphus signatellus</i> ¹	S	SC	G3	0.0042	1

Species	PH	CH	D	I (L;E)	"G"	Species	PH	CH	D	I (L;E)	"G"
<i>Ochthebius praetermissus</i> ¹	F	NA	G3	0.0128	1	<i>Hydroglyphus major</i> ¹	S	AM	G1	0.0042	1
<i>Ochthebius mediterraneus</i> ¹	S	EM	G2	0.0128	1	<i>Hydroporus feryi</i> ^{*1,2,3}	F	NA	G4	0.1152	2.698
<i>Hydrophilus pistaceus</i> ¹	F	WM	G3	0.0128	1	<i>Hydroporus obsoletus</i> ^{*2,3}	S	TEM	G1	0.1197	2.818
<i>Laccobius revelierei</i> ^{1,3}	F	AM	G2	0.0205	2.076	<i>Hydroporus pubescens</i> ^{*1,2,3}	P	CEM	G4	0.0458	2.441
<i>Laccobius atrocephalus</i> ^{1,2,3}	P	AM	G4	0.0076	1.849	<i>Hydroporus memnonius</i> ¹	S	EM	G1	0.0042	1
<i>Laccobius orientalis</i> ^{*1,2}	P	IM	G4	0.0471	1.364	<i>Hydroporus analis</i> ^{*2,3}	F	M	G1	0.0804	2.75
<i>Laccobius atratus</i> ^{1,2,3}	P	EM	G4	0.0387	1.744	<i>Hydroporus tessellatus</i> ^{*1,2,3}	P	CEM	G4	0.0665	2.704
<i>Laccobius pommayi</i> ¹	P	NA	G3	0.0218	1	<i>Stictonectes escheri</i> ¹	F	WM	G4	0.0173	1
<i>Laccobius bipunctatus</i> ^{1,2}	S	CEM	G2	0.0095	1.731	<i>Stictonectes optacus</i> ^{1,3}	S	WM	G4	0.0205	2.781
<i>Berosus affinis</i> ^{*1,2,3}	P	TEM	G4	0.0530	1.578	<i>Stictonectes samai</i> ^{*1,3}	P	NA	G4	0.1382	2.94
<i>Berosus spinosus</i> ¹	F	P	G3	0.0128	1	<i>Stictotarsus procerus</i> ¹	S	NA	G3	0.0084	1
<i>Berosus signaticollis</i> ¹	S	P	G3	0.0042	1	<i>Agabus africanus</i> ^{*1,2,3}	P	En	G1	0.0548	2.652
<i>Anacaena lutescens</i> ^{1,2,3}	P	H	G4	0.0266	1.912	<i>Agabus didymus</i> ^{*1,2,3}	P	TEM	G4	0.0422	2.384
<i>Anacaena globulus</i> ^{1,2,3}	P	EM	G4	0.0088	2.162	<i>Agabus nebulosus</i> [*]	F	CEM	G4	0.0637	2.719
<i>Anacaena bipustulata</i> ^{1,2,3}	P	EM	G4	0.0079	2.148	<i>Agabus bipustulatus</i>	P	SC	G4	0.0152	2.462
<i>Helochares lividus</i> ^{*1,2}	P	TEM	G4	0.0693	1.446	<i>Agabus biguttatus</i> ^{*3}	S	EMA	G4	0.1741	3
<i>Enochrus nigrinus</i> ¹	P	CEM	G4	0.0264	1	<i>Ilybius bedeli</i> [*]	S	NA	G1	0.0532	2.884
<i>Enochrus affinis</i> ¹	S	P	G1	0.0042	1	<i>Dytiscus circumflexus</i>	S	CEM	G2	0.0128	1
<i>Enochrus fuscipennis</i> ¹	F	EM	G4	0.0173	1	<i>Rhithrodytes numidicus</i> [*]	P	NAF	G1	0.0804	2.75
<i>Paracymus scutellaris</i> ¹	S	EM	G4	0.0084	1	<i>Graptodytes fractus</i> ^{*1,2,3}	F	M	G4	0.1152	2.698
<i>Hydrobius fuscipes</i> ¹	S	H	G2	0.0128	1	<i>Graptodytes ignotus</i> ^{*1,2,3}	S	M	G4	0.0487	2.673
<i>Hydrobius convexus</i> ¹	S	WM	G1	0.004	1	<i>Graptodytes flavipes</i> ^{1,2,3}	P	TEM	G4	0.0234	2.185
<i>Hydrochus flavipennis</i> ^{1,2,3}	P	EM	G4	0.003	2.056	<i>Graptodytes pietrii</i> ^{1,3}	F	WM	G4	0.0329	2.342

Species	PH	CH	D	I (L;E)	"G"	Species	PH	CH	D	I (L;E)	"G"
Hydrochus smaragdineus ^{1,2,3}	S	WM	G2	0.001	2.17	<i>Graptodytes varius</i> ^{*1,2,3}	P	EM	G2	0.0609	2.56
<i>Hydrochus grandicollis</i> ^{1,2}	P	M	G4	0.009	1.521	<i>Hygrotes lagári</i> ¹	P	WM	G4	0.0312	1
<i>Coelostoma hispanicum</i> ^{1,2,3}	P	WM	G4	0.007	1.85	<i>Deronectes perrinae</i> ^{*1,3}	F	NA	G1	0.0925	2.921
<i>Hydrocyphon</i> sp. ^{1,2}	F	–	G2	0.008	1.644	<i>Deronectes fairmairei</i> ^{1,2,3}	S	WM	G4	0.0065	2.311
<i>Elodes</i> sp. ¹	S	–	G3	0.004	1	<i>Melodema coriacea</i> ²	S	TEM	G1	0.0314	2
<i>Cyphon</i> sp. ³	S	–	G1	0.038	3	<i>Rhantus suturalis</i> ¹	S	SC	G3	0.0042	1
Dryops peyerimhoffi ^{1,2}	P	NA	G4	0.032	1.42	<i>Liopterus atriceps</i> ¹	S	WM	G2	0.0173	1
<i>Dryops sulcipennis</i> ^{*1}	F	TEM	G4	0.045	1	<i>Colymbetes fuscus</i> ¹	P	P	G3	0.0084	1
<i>Dryops algericus</i> ¹	S	TEM	G4	0.012	1	<i>Colymbetes schildknechti</i> ¹	S	WM	G3	0.0084	1
Pomatinus substriatus ¹	S	TEM	G2	0.008	1	<i>Hydrovatus cuspidatus</i> ¹	S	SC	G3	0.0084	1
<i>Oulimnius rivularis</i> ^{1,2,3}	P	EM	G4	0.010	2.095	<i>Hydrovatus clypealis</i> ¹	S	EM	G3	0.0042	1
Oulimnius troglodytes ^{1,3}	F	EM	G4	0.015	2.462	<i>Hydaticus leander</i> ¹	P	ACM	G4	0.0173	1
<i>Limnius intermedius</i> ¹	P	EM	G3	0.012	1	<i>Nebrioporus clarkii</i> ^{1,2}	P	M	G1	0.0137	1.844
<i>Esolus filum</i> ^{1,2}	S	NA	G1	0.013	1.844	<i>Nebrioporus cerisyi</i> ¹	P	CEM	G4	0.0084	1
Potamophilus acuminatus ¹	S	P	G3	0.004	1	<i>Nebrioporus</i> sp. ^{1,2}	S	–	G2	0.0137	1.844
Helophorus maritimus ^{1,3}	F	M	G4	0.020	2.076	<i>Cybister tripunctatus</i> ssp. <i>africanus</i> ¹	F	ACM	G3	0.0084	1
<i>Helophorus alternans</i> ^{1,2}	F	EM	G4	0.016	1.404						

asterisk (*) indicates species whose reciprocal information species-factor exceeds value 0.04. PH, phenology; P, permanent; F, frequent; S, seasonal; CH, chorology; En, endemic; NA, North African; TEM, Turano-Europeo-Mediterranean; ACM, Afrotropico-Centralasiatic-Mediterranean; EM, Europeo-Mediterranean; EMA, Europeo-Mediterraneo-Asiatic; CEM, Centralasiatic-Europeo-Mediterranean; IM, Indo-Mediterranean; AM, Afrotropico-Mediterranean; WM, West-Mediterranean; M, Mediterranean; P, Palearctic; H, Holarctic; SC, Subcosmopolitan; D, distribution in the study area; G1, occurring in the Kroumir and Mogods mountains; G2, also occurring east of the Tell mountain chain; G3, found only in Bizerte and Cap Bon regions; G4, widespread throughout the study area. Recently recorded species for Tunisia are indicated in bold. Altitudinal distribution; lowland (1), midland (2), highland (3).

Table. 1 Values of mutual information I (L; E) and the barycenter "G" for every species.

minatus, *Dryops peyerimhoffi*, and *Pomatinus substriatus* [36]. A particular attention was given to the Maghrebin endemic *Esolus filum* since the citations in Algeria are old and the occurrence of the species in North Africa refers to the recent catch conducted in the Moroccan Rif [37]. Hydrochidae is a monogeneric family with about 180 species occurring on all continents. All species are truly aquatic, living in well-vegetated stagnant water, and/or at the edges of very slowly flowing water [1]. Boumaïza [15] and Hansen [38] recorded two *Hydrochus* species from Tunisia. We sampled also *Hydrochus smaragdineus* (**Table 1**) for the first time [39].

Helophoridae is a monogeneric family with about 185 species, more or less confined to the Holarctic Realm [1]. Most species seem to prefer standing shallow water with plenty of organic debris, such as edges of small-to-medium sized water bodies [40]. Thirteen species of *Helophorus* are known in Tunisia [12, 38]. The checklist of Helophorids of Tunisia was bettered by new records of three species (**Table 1**): *Helophorus milleri*, *Helophorus paraminutus*, and *Helophorus cincticollis* [41]. Hydrophilidae consists of about 2652 species in 174 genera occurring on all continents, among them about 70% are aquatic [1]. In total, 21 *Hydrophilid* species were recently found. The most interesting ones from the zoogeographical point of view are *Enochrus nigritus*, *Enochrus affinis*, *Laccobius revelierei* (all newly recorded for Tunisia), and *Laccobius orientalis* and *Berosus spinosus* (newly recorded for North Africa) [42].

An updated checklist of the aquatic adephagan Coleoptera includes a total of 90 species, of them 57 were sampled in the study area (three Gyrinidae, six Haliplidae, one Paelobiidae, one Noteridae, and 46 Dytiscidae). *Hydroglyphus major* is recorded for the first time from Tunisia [43]. Dytiscidae have approximately 520 undescribed species. Gyrinidae represent a family of medium diversity, with an estimated 1000 species. Water beetles display their greatest diversity in the tropics except for Haliplidae and Helophoridae. Haliplidae are distinctly more diverse in the Holarctic Realm than in any of the tropical regions, although most tropical countries are still rather poorly examined [1].

3. Ecological traits of water beetles

3.1. Diversity and geographical pattern of water beetles

Species were categorized into three groups according to their adult phenology, following the approach of Valladares and Garrido [44]; permanent species (found over the course of the year), frequent species (encountered in three seasons), and seasonal species (occurring only during one or two seasons). The phenology of species is based on the presence of the adults since the capture of larvae is sporadic and requires an appropriate methodology [45]. The distribution of species in the studied areas in a transect from west to east took into account the differences in geological (landform localization) and hydrological (basin connectivity) characteristics. Four distributional categories of the water beetle species are distinguished according to the areas in which each species occurs (**Figure 1** and **Table 1**); 19 species occurring only in the Kroumir and Mogods Mountains (G1), mainly Hydraenidae and Hydroporinae (Dytiscidae) that are pollution-sensitive and rheophilous collected primarily from montane streams of the Aïn Draham region that are safe from any anthropogenic activities, 15 species

also occurring east of the *Tell* mountain chain (G2), 19 species occurring only in the Bizerte and Cap Bon Peninsula (G3), and 70 species widespread throughout the study area (G4).

Beetles living in freshwater are strongly influenced by physicochemical and biological factors [46]. The chronology of appearance of the sampled species may be attributed to the flow of rivers, which may be temporary. The temporal appearance of species also is affected by a spatial variation that can hide the chronology of their emergence in each stream. Indeed, the study sites belong to different bioclimatic regions that largely influence water permanence, trophic factors, and hence, population dynamics (intensity of drift and migration and distribution of the fauna according to the availability of prey and competition).

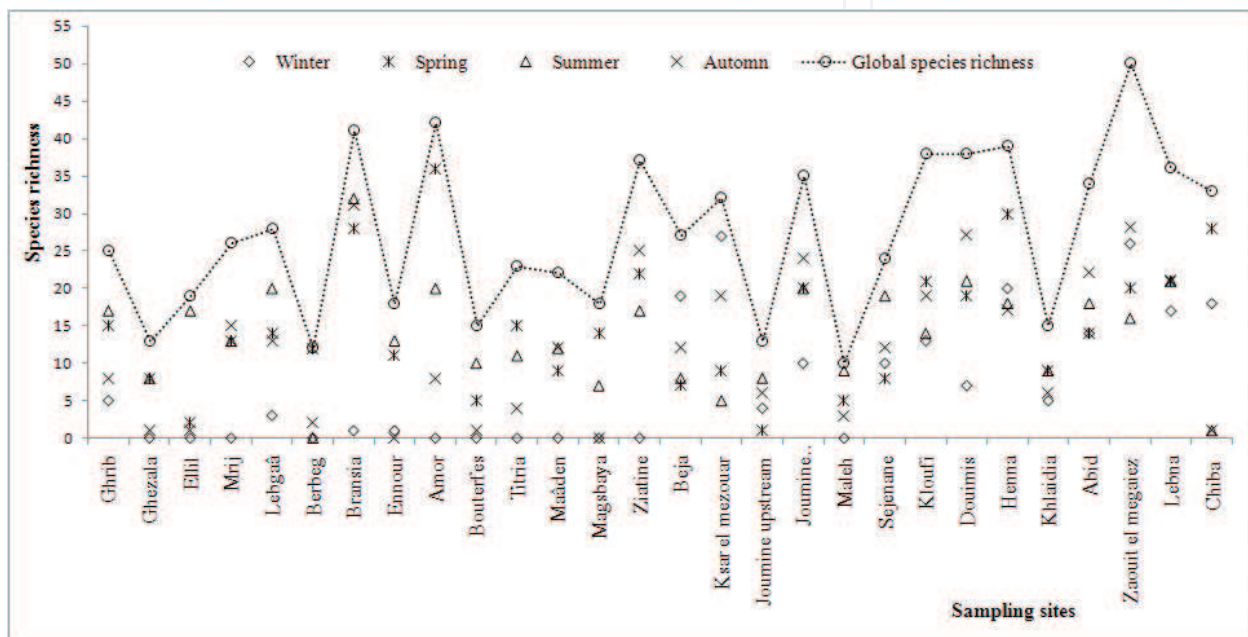


Figure 2. Seasonal and spatial variation in species richness of water beetles.

The species richness of water beetles follows seasonal fluctuation (Figure 2). The frequency and abundance of their adults attenuate considerably and even are absent when the environmental conditions become unfavorable in winter because of decreased water temperature, high turbidity, and the reduction of the aquatic vegetation as food, and refuge for the benthic community. The seasonal succession of species in temporary waters affects trophic structure, adaptations to drought, and traits common to most successful taxa, including highly flexible life cycle, temperature-dependent development, diapause or otherwise protected eggs, and high dispersal ability [46]. Among the main factors affecting community structure are runoff from agricultural areas, vegetation cover, and water chemistry [47]. Except for Noteridae, water beetles have terrestrial pupae. The life cycles of these species may include larval or adult terrestrial stages that minimizes the likelihood of their occurrence in the aquatic environments. In groups such as Dytiscidae and Elmidae, larvae and adults are aquatic. In other groups, such as Scirtidae, only larvae are aquatic. Hydraenidae and the hydrophilid (Hydrochinae and Helophorinae) have only adults as the aquatic stage [48]; they live as larvae in a dry cocoon in an excavated cavity above the water level, and can leave and return to it as

adults [49], which minimizes the chance of capture. The overall phenology of the water beetle species reveals highest abundance and frequency in summer and in autumn. The phenological categories revealed a predominance of permanent species compared with frequent and seasonal species, with slight differences in abundance levels. Permanent and frequent species follow the overall phenological pattern, whereas the seasonal species show a spring maximum of abundance, which decreases toward a winter minimum [50].

Permanent species (52)—They may be considered the most eurytopic species in terms of environmental variables. Their majority are aquatic as larvae and imagoes (Gyrinidae, Haliplidae, Dytiscidae, and Elmidae). However, this more complete aquatic existence hides a variability of their existence in each river taken separately. The presence of each species can be used for the evaluation of its habitat preference [51].

The species exhibiting an autumnal peak of abundance are *Noterus laevis*, *Yola bicarinata*, and *Ochthebius viridescens*. *Haliplus lineaticollis*, *Peltodytes rotundatus*, *Laccophilus minutus*, *Hydrochus flavipennis*, *Berosus affinis*, *Helochaeres lividus*, *Hydraena leprieuri*, *L. orientalis*, and *Laccobius atratus* were most abundant in summer and autumn. Three species, *Hydroporus pubescens*, *H. rivularis*, and *Ochthebius dilatatus*, were most abundant in spring and in autumn, whereas only *Graptodytes flavipes* was maximally abundant in spring and in summer. *B. affinis* had a considerable population increase during spring, summer, and autumn, coinciding with a rise in water temperature and vegetation growth. The species displayed a phenology close to that recorded in the province of Palencia in Northern Spain with a peak of abundance in summer, but a light winter proliferation [44]. This phenology was identical to that observed by Aouad [52] in ecosystems of Morocco, with high abundance of larvae in spring. *H. lividus* and *Aulacochthebius exaratus* maintained similar abundance patterns during the annual cycle, similar to their phenology observed by Valladares and Garrido [44] in Palencia. *Agabus bipustulatus* is regarded by Ribera et al. [53] as the most abundant species of the genus year-round in the Pyrenees, whereas *Hygrobia hermanni* is maximally abundant during winter and spring. We found *Agabus didymus* the most abundant species year-round, and *H. hermanni* was uncommon during all seasons. According to Bertrand [54], *Hyphydrus aubei* is present with quasi similar seasonal abundances, with a collection of larvae during April in central and southern Europe and North Africa. We found this species slightly more abundant in spring and in summer. According to Millán [55], *N. laevis* is present year-round, but its abundance decreases during autumn in the south-eastern Iberian Peninsula. This is different from our observations that show an autumnal increase. Valladares and Garrido [44] mentioned that populations of *Hydroglyphus geminus* increase in summer and then decrease in autumn, whereas *Anacaena lutescens* is encountered only in winter. However, in the present study, we observed *H. geminus* more or less equally abundant year-round, and found *A. lutescens* all year but most abundant in spring and in summer. *H. flavipennis* is a permanent species with slightly higher abundance in summer and in autumn. According to Valladares and Garrido [44], it belongs to the group of frequent species, but it is absent in spring.

Frequent species (31 species)—they are mainly more localized montane species. These species exhibit low abundance associated with low frequencies and restricted distribution. The majority of the species exhibit similar seasonal abundance patterns. However, *Graptodytes*

fractus and *Hydroporus feryi* present two peaks of abundance, in summer and in autumn. *Helophorus algiricus* is maximally abundant in spring, whereas *L. revelierei* is most abundant in summer. Sixteen species in this group were not captured in winter, which is characterized by a disturbance of microhabitats due to the flood effect affecting the majority of sites. Six species were not captured in summer when temporary streams become dry. Two species, *Helophorus asturiensis* and *Helophorus alternans*, were rare in autumn and in winter, became abundant in spring, and then were absent in summer. They are regarded as seasonal species by Valladares and Garrido [44], appearing only in winter and in spring with low abundance. Valladares et al. [45] noted that *H. lividus*, a permanent species in our study, and *Enochrus fuscipennis*, which have similar sizes, habitats, and prey type, exhibited peak abundance in spring and in autumn. This may be interpreted as an adjustment of their biological cycles to avoid the interspecific competition for shared trophic resources.

Seasonal species (40)—their absence from some sites may be accounted for sampling effort and/or scarcity. Their richness decreased from spring to winter, probably due to their ecological requirements. Abellán et al. [56] consider measurements based on richness, abundance, or evenness, which are usually used in the evaluation of the effects of environmental degradation on biodiversity, to be highly influenced by sample size, sampling effort, and the type or complexity of the habitat. Valladares and Garrido [44] observed that *Paracymus scutellaris* and *Dryops algiricus* exhibited the same phenological pattern in Spain, whereas *Berosus signaticollis* had clear peak abundance during these seasons. In the present work, the first species was found in spring and in summer only, the second species in summer and winter only in low numbers, and only a single specimen of the third species was taken (during spring). *H. atrata* was collected only in one site during September. It is present during four seasons, particularly in spring, in the Channel of Castile in Northern Spain [45]. In the same way, *Rhantus suturalis* was captured in a well during the spring, but it is permanent in the Pyrenees and has its population peak in winter [57]. *Hydrobius fuscipes* was collected only in April in our study, but in Spain, it is abundant in autumn and in spring and absent in winter [44].

The geographical distribution was analyzed by chorotype based on distributional patterns that are deduced from a comparative analysis of geographical ranges of species [58]. The fauna of Tunisia, as well as all of North Africa, is a heritage of Eurasian and Afrotropical elements. However, during the Pliocene, the isolation from Europe blocked the arrival of several European lineages. The desertification of the Sahara during the Holocene impeded the northward movement of Afrotropical species. These two facts explain the relative poverty of the water beetle fauna compared to less isolated zoogeographic regions in the world [32]. The chorological category corresponding to each species is given in **Table 1**. The most important chorotypes are Europeo-Mediterranean (19.2%), North African (15.8%), West-Mediterranean (12.5%), Turano-Europeo-Mediterranean (12.5%), and Mediterranean (8.3%). The number of endemic species is low, about 2.5% of the total fauna. For the species of the genus *Hydraena*, as for many other organisms of the chorotype North African (NA), the Sahara desert rather than the Mediterranean Sea forms a biogeographical limit. The majority of *Hydraena* species are North African. The main exchanges with Europe took place in the west where the Strait of Gibraltar is situated [32]. Abellán et al. [59] considered the biodiversity of freshwater systems to be endangered, especially in Mediterranean semiarid regions like our study area. Northern

Tunisia has a rich and endemic biota that is threatened by the development of surrounding land-crop irrigation. These freshwater habitats and species need more protection in order to preserve the biodiversity of the freshwater ecosystems of North Africa. Endemic species from Tunisia (En) comprises three species *H. kroumiriana*, *L. irmelae* and Dytiscidae (*Agabus africanus*). The distribution of *H. kroumiriana* is restricted to a small montane stream located in Northwestern Tunisia. It is threatened with extinction according to the categories and criteria established by the IUCN [18]. *L. irmelae* apparently has a small population since less than four adults were captured per site over the course of a year. *A. africanus* is more dispersed toward the east (Cap Bon Peninsula) but is still scarce.

The fauna of North Africa probably originated from the passage of Euroasian species to the African continent as a result of plate tectonics (in the Tortonian), leading to the connection of the two continents. The Mediterranean Sea and the Atlantic Ocean were later connected (in the Pliocene), thereby isolating the faunas of the two continents [20]. The origin of the water beetle fauna in Northern Tunisia reflects the history of the Mediterranean basin. During the secondary era, the coastal massifs of the Rif, as far as the Kroumir, were an emerged part of a continent or more probably an archipelago, the Tyrrhenid, which spread over what is now the western Mediterranean between Spain and Italy [32]. The Eocene and Oligocene transgressions reduced the Tyrrhenid to the Betico-Rifan massif separated from Europe by the North-Betican trough and from Africa by the South-Rifan trough and by some islets near the Kabylie. These lands remained emerged up to the present time. North Africa was joined to Eurasia at the end of the Miocene, and the Mediterranean, thus enclosed, dried up. During the Pliocene, a transgression covered the Tyrrhenid and the Strait of Gibraltar divided the Betico-Rifan into two parts [60]. These events provide a hypothesis explaining the chorological aspects of the current water beetle fauna of Tunisia and North Africa.

3.2. Altitudinal distribution of water beetles

The northern part of Tunisia comprises several orographic areas: the *Tell* (altitude ranges between 400 and 800 m), the *haut-Tell* and the *Dorsale* culminating at *Djebel Châambi* (1544 m), with a width of 40 km in the west and becoming narrow in the east toward the *Cap Bon Peninsula* [21]. As larger number of species are sensitive to this ecological parameter, the more significant are their role in the biotope [61]; an ecological study of the geographical distribution of water beetles in the mountains of Northern Tunisia was carried out with an analysis of the effect of altitude on the distribution of 123 species collected from 64 sampling sites. Species richness was analyzed at different altitudinal levels and the indicator species were determined by establishing their altitude profile in terms of reciprocal species-factor information (see Touaylia et al. [62]). The information related to the altitudinal gradient gave a score of $I(L; E) = 0.702$, while maximum entropy, which depends only on the number of altitudinal levels considered, was $H(L) \max = \log_2 [NK] = \log_2 3 = 1.09$. The ratio between those two scores, which determines the sampling quality, was 0.644. This ratio shows that the altitudinal factor has been sufficiently sampled; however, some information is lost because of the high frequency (76.6%) of sampling sites in the first altitudinal level. The variation in aquatic beetle species richness at different altitude levels is shown in **Table 1**; overall, species richness decreases with increasing altitude. Species richness decreases within the different families

with increasing altitude [62]. In an overall regional survey, we did not analyze the ecological features of all species because it would not be necessary to analyze features of species not having “useful information”, and it would be difficult to work with such a large number of species. An indicator value is attributed to every altitude profile as high as the information score that it gives. The species with the highest I(L; E) scores are the most sensitive to the altitudinal factor and could be considered as altitude indicator species. Their high I(L; E) value highlights the important role of altitude in the distribution of species in the study area. Among the species whose reciprocal “species/altitude” information exceeds 0.04, those having a more significant altitude profile from the corrected frequencies and comprising a less variable spectrum of the altitudinal factor were selected as being representative (indicated with an asterisk). The ecological influence of altitude on the distribution of water beetles was demonstrated through a determination of indicator species linked to the altitudinal gradient. The assessment of the barycenter abscissa value is obtained from the set of information provided by the species’ altitude profiles, highlighting those that give more information in relation to the considered factor ($I(L; E) > 0.04$). In this way, an ordering was established in the set of species, based on increasing “G” values, that is equivalent to classifying species along an altitudinal gradient. Species having similar barycenters are expected to possess the same ecological behavior, and the barycenter abscissa of the profile can be taken as an index of its ecological optimum in terms of the considered factor [63]. However, the frequency profile of the different species needs also to be taken into account. The analysis of the barycenter abscissa reveals that species having a low value are highly localized. Species whose profile shows an average barycenter have greater amplitude. Such phenomena are often very significant, as has been shown in similar ecological studies [64]. Taking into account their altitudinal preferences, the 30 representative species are categorized into five groups (**Table 1**):

**Species present along the entire altitudinal gradient*—several altitudinally ubiquitous species of Hydraenidae, Hydrophilidae, Helophoridae, and Dytiscidae. *H. leprieuri* (7–588 m) is endemic in North Africa [32]; it lives in clear, preferably flowing, waters under detritus and stony substrata with rocks and gravel providing with it a homochromy for avoiding predators. *Limnebius pilicauda* (2–588 m)—a member of the Maghrebini element— was captured at an altitude of 1300 m in Morocco [34]. It was collected in shady watercourses in the region of Aïn Draham as well as in lowland, lentic, vegetated streams with muddy and gravelly bottoms. *L. theryi* (16–588 m)—endemic in Algeria and in Tunisia [34]—is more abundant at high altitudes. Its broad ecological profile allows it to live in a variety of habitats. *B. affinis* is an ubiquitous specie, showing great ecological plasticity, occurring in a variety of aquatic ecosystems (lagoons, ponds, springs, rivers, and ditches) associated with muddy substrates. Its altitudinal distribution ranges from 5 to 1400 m [65]. It has been found associated with vegetation, sometimes in muddy and eutrophic as well as in clear waters [66]. It has a wide altitudinal distribution (2–588 m) and also high abundance and frequency. *H. algiricus* is a representative of the *obscurus* complex in North Africa. It occurs in a variety of shady places (5–2000 m) in Morocco [65]. Its altitudinal range is wide (6–631 m) with a greater abundance at high altitude sites. It was found along the banks of streams rich in organic matter. *H. feryi* shows a preference for highland sites, but rarely occurs in lowland areas; its wide altitudinal level (2–614 m) means it is an ubiquitous species. It occupies the same habitats as *H. pubescens*.

Its highest abundance is in sites with bryophytes and mosses. *H. pubescens* was encountered on plains and low mountains in stagnant fresh or brackish waters [67]. It is more abundant in clear, well oxygenated, fast-flowing, but poorly vegetated waters (2–588 m). *Hydroporus tessellatus* is a typical species of subalpine levels. It has a wide ecological valence, occurring in lotic or lentic habitats [26]. It was captured at sites whose altitude ranges between 16 and 588 m. Its abundance increases considerably at higher altitudes, and it becomes scarcer at lower altitudes. *Stictonectes samai* is well represented in highland areas; in contrast, it was taken at a single lowland site. *Agabus brunneus* has been collected from flowing waters of small streams [54]. It was found at both lowland and highland sites (2–588 m), but it is not represented at mid-altitude sites. *A. didymus* is considered a montane species (645–1295 m), with greatest affinity for altitudes between 900 and 1200 m, where it is abundant [26]. It occurs in clear running waters of the Alps [54]. In our study, it was captured in the same habitat type up to 588 m. *Agabus nebulosus* lives in stagnant waters in the lower Pyrenees (>2000 m) [67]. It was captured in lentic (pond and irrigation canal) and lotic (river and high mountain) habitats [26]. In our collections, it was also found in lowland areas (16 m) with abundant vegetation and reached its highest altitude at 631 m. *Ilybius bedeli* (3–588 m) is scarce at lowland altitudes, but well represented at highland sites. It was recorded by Normand [12] and Vigna Taglianti et al. [58] from clear, flowing waters of mountainous part of Aïn Draham, Camp de la Santé, and El Feidja. *G. fractus* (2–714 m) is abundant mainly in the highest mountainous regions of Northwestern Tunisia, as also recorded by Normand [13]. *Graptodytes ignotus* is uncommonly distributed along an altitudinal gradient from 16 to 714 m. It has a tendency to sandy and gravelly sediments in clear, flowing waters of shady mountainous regions. *Graptodytes varius* (2–588 m) has highest abundance from streams of the Bni Mtir Dam basin. *Deronectes perrinae* is a highland species found in mountains (up to 631 m). However, one adult was collected at lowland (7 m), possibly carried there by river debris.

***Species present only in lowland areas**—*A. exaratus* was encountered in a small vegetated inlet stream with a substratum of gravel and sand at 265 m [26]. Its ecological requirements vary according to geographic area. It can tolerate a wide range of environmental conditions [65]. Its altitudinal range in the study area varied between 3 and 176 m. *Dryops sulcipennis* is found in two different kinds of habitats, bogs, and flowing waters [69]. It was collected at lowland sites (2–237 m). *P. rotundatus* lives among filamentous algae in lakes, pools, ponds, rivers, marshes, brooks, and streamlets, and shows a preference for running water among vegetation of *Utricularia* and *Nuphar* [70]. It was encountered at sites located at altitude from 2 to 236 m.

***Species present only in lowland-midland areas**—*O. viridescens* was found in brackish as well as inland waters [71]. It lives mainly in lowland sites (2–255 m). It is associated with the roots of vegetation such as *Juncus multiflorus* and *Typha angustifolia*. *L. orientalis* can be considered lowland; it is very frequent in sites at low altitude (6–255 m). *H. lividus* is localized among mud and detritus on the edge of temporary ponds, lakes, lagoons, and rivers [66]. It was captured at altitudes ranging from 6 to 255 m. *N. laevis* (2 and 255 m) was found in stagnant waters with rich vegetation, but sometimes also in slowly flowing waters as mentioned by Vondel and Dottner [70]. *L. minutus* shares the same habitat type as *Laccophilus hyalinus*, but it shows a preference for stagnant waters and has been captured at altitudes up to 1500 m [54]. The altitude range of present collections lies between 2 and 484 m.

***Species present only in midland-highland areas**—*Hydraena testacea* lives in ponds, slow-flowing, oxygenated small streams, or other stagnant waters with a slimy, eutrophic substratum invaded by algae [26, 72]. Its distribution in Tunisia is limited to two closely approximate sites from the Aïn Draham forest (484–588 m), categorized as a threatened species at local scale. *Hydroporus obsoletus* lives exclusively in hollows and quiet stream edges of mountains [67]. It was collected at altitudes between 329 and 588 m. *Hydroporus analis* is typical of coastal brackish waters [67]. The habitat of our collection (484–588 m) is characterized by fast flowing, limpid, oligotrophic, unmineralized water, where it was recorded by Pederzani and Schizzeroto [16]. *Rhithrodytes numidicus* was recorded from small streams of Fernana and Aïn Draham Mountains [12]. Our captures are restricted to the Bni Mtir Dam basin (314–588 m). It was also collected in underground waters (wells) as a stygoxene epigeal species.

***Species present only in highland areas**—*Agabus biguttatus* may be considered montane. In North Africa, it lives in forest streams (3200 m) [68]. Its occurrence in the study area is limited to several streams of the Bni Mtir Dam basin (Northwestern Tunisia) at altitudes between 563 and 631 m. It occupies a habitat type characterized by steep slopes, a substratum predominantly of stone and gravel, poor vegetation, and well oxygenated, fast-flowing waters. The mean value of the mutual information is higher when species have more affinity for several classes of the altitude. The importance of a descriptor corresponds to its effectiveness to select species in order to know the zoo-ecological groups among them [61]. Jacobsen [73] indicated that mean local and zonal family richness decreased by about 50% from sea level to 4000 m; local richness declined linearly from sea level to 1800 m.

The species richness of water beetles decreases with increasing altitude. This may be explained by the fact that some species present in lowland streams were not found at higher altitudes (Table 1). Furthermore, it can also be attributed to the fact that the majority of sampled sites were in the first altitudinal level. Also, there was a decrease in new species with the accumulation of new records. Five species were newly recorded in the mid-altitude level, whereas 25 species disappear in it. Sixteen species were added in the high altitude level to those of the mid-altitude level, with the disappearance of 18 species; seven species were new, and 69 were absent in the high altitude level in comparison with the low altitude level.

4. Conclusion

The water beetles in Tunisia are poorly studied not only in comparison with the European fauna but also with other zoogeographical areas. The present conducted survey aims at bettering the knowledge on this freshwater fauna. The species richness of water beetles is updated by new records; it can be bettered through samples from central and southern Tunisia. This checklist seems to better the knowledge of the diversity of the water beetles' habitats and provides a solid basis for further research, focusing on macroinvertebrates in order to better direct monitoring conservation projects, and to assess the effects of anthropogenic activities on these fragile ecosystems. The fauna of Tunisia, as well as all of North Africa, is a heritage of Eurasian and Afrotropical elements. However, during the Pliocene,

the isolation from Europe blocked the arrival of several European lineages. The desertification of the Sahara during the Holocene impeded the northward movement of Afrotropical species. These two facts explain the relative poverty of the water beetle fauna compared to less isolated zoogeographic regions in the world [32]. These aquatic insects are heterogeneous in their local and world distribution. Their assemblage is structured by physicochemical parameters. They include indicator species (water quality, altitude, etc.). Altitude could be considered among the physical factors that affect distribution of stream macroinvertebrate communities, but its effect is also combined with other environmental variables such as temperature, substratum, water flow, and stream geomorphology, particularly in streams extending along altitudinal gradients [74]. Water permanence and depth were considered by Williams et al. [75] among the main environmental variables explaining invertebrate assemblage structure. The present study was restricted to the northern part of Tunisia. The sampled sites ranged between 1 and 714 m, which is a rather limited altitudinal gradient. In many geographical areas, 714 m would hardly be considered “high altitude.” This can make difficult a comparison with other areas in which the habitats typical of the Tunisian “lowland” are found above such an altitude. Therefore, the distribution of the species has to be related to the distribution of habitats, as the same species can be found at different altitudes in different areas, depending on where suitable habitats are found. Further sampling is required to confirm these results, especially in higher mountains in central and southern Tunisia, since those in central Tunisia rise to 1544 m.

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